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POST EARTHQUAKE INVESTIGATION FIELD MANUAL FOR THE STATE OF KENTUCKY



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POST EARTHQUAKE INVESTIGATION FIELD MANUAL FOR THE STATE OF KENTUCKY

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in cooperation with

Transportation Cabinet
Commonwealth of Kentucky

and

Federal Highway Administration
U.S. Department of Transportation

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16. Abstract The rapid assessment of a bridge structure's safety and functionality is an essential component to restoring vital lifeline routes after a major earthquake. Appropriate posting categories are used to assure the safety of the traveling public. The objective of this manual is to provide a rapid and efficient method of inspecting bridge structures after an earthquake. The primary users of this manual are intended to be the initial Kentucky Transportation Cabinet personnel who will initially reach the bridge sites. It is recognized that such first-line personnel will possess a variety of backgrounds and, therefore, a systematic method of evaluating the damage is necessary. This manual represents a rapid and efficient method of inspecting damaged bridge structures in a uniform manner. Evaluation forms are intended to be filled out electronically, whereby, the resulting posting will be determined through an internal program developed from the expert opinions of the authors. Appropriate posting actions and recommendations are then produced from the inspection results on the evaluation forms. The information gathered on these forms will also be used to prioritize the follow-up inspections by trained bridge engineers and plan repair efforts.					
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DISCLAIMER

The information presented in this manual is believed to be correct. However, the authors and sponsoring agencies assume no responsibility for its accuracy or for the opinions expressed herein. The material presented in this manual should not be used or relied upon for any specific application without competent examinations and verification of its accuracy, suitability, and applicability by qualified professionals. Users of information from this publication assume all liability arising from such use.

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In 2001, the Kentucky Transportation Cabinet contracted with Dr. Issam E. Harik at the University of Kentucky to develop a manual and training program for post earthquake safety evaluation of highway bridges.

Dr. Issam E. Harik, Dr. Ann G. Sardo and Mr. Thomas E. Sardo have prepared this manual for the post earthquake evaluation of highway bridge structures in Kentucky. Guidance for this project was provided by the Kentucky Transportation Cabinet.

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1 INTRODUCTION

1.1 Objective and Scope

Highway bridge structures have historically presented significant vulnerabilities during major seismic events. The purpose of this manual is to provide guidelines and procedures for the post earthquake investigation of highway bridge structures in Kentucky. The procedures are intended to provide a uniform approach for rating damage to bridge structures. The philosophy is to accept a certain level of expected damage while acknowledging that bridge structures maintain a high degree of residual strength beyond current design levels.

The rapid assessment of a structure's safety and functionality is an essential component to restoring vital lifeline routes. Appropriate posting categories (e.g. bridge open, travel with caution, reduced speed limit, emergency vehicle use only, bridge closed) are used to assure the safety of the traveling public. The posting categories and associated recommendations are color coded to correspond to the threat level identification system adopted by the Federal Department of Homeland Security. For example, Green represents a low damage state of the bridge structure, Blue represents a guarded damage state, Yellow represents an elevated damage state, Orange represents a high damage state and Red represents a severe damage state. It is intended that these results remain consistent with the level of safety appropriate in the immediate post-disaster situation. An important objective is to assess the damage and provide the necessary information for emergency relief and reconstruction assistance.

The scope of this manual deals primarily with the technical aspects of making post earthquake investigations and not the administration nor organization of inspection teams. Likewise, seismic hazards such as damage to utility lines on bridge structures, retaining wall structures, and roadways are not addressed in this document.

Since the major seismic hazard in Kentucky results from the New Madrid Seismic Zone in the rural southwestern portion of the state, it is expected that professional bridge engineers would be delayed in traveling to the damaged locations. The primary users of this manual are intended to be the initial Kentucky Transportation Cabinet personnel who will reach the bridge sites first. It is recognized that such first-line personnel will possess a variety of backgrounds and, therefore, a systematic method of evaluating the damage is necessary. The tools in this manual are intended to provide a rapid and efficient method of inspecting these structures in a uniform manner. A key component to any disaster response plan is the proper training and rehearsal drills for qualified personnel.

1.2 Background

This manual is intended to be a field document and used as a reference during the inspection of post earthquake damage to highway bridges. A training course is intended to precede the usage of this manual. A CD ROM is also available for a more complete compilation of damage photos and possible damage scenarios.

2 OVERVIEW OF BRIDGE SAFETY EVALUATION PROCEDURE

The main objective in the inspection criteria presented in this manual is to prepare Kentucky Transportation Cabinet personnel with varied backgrounds for the visual damage inspection of highway bridges immediately following an earthquake. The purpose of this inspection is to post the bridge structure with one of five possible identification postings signs:

- GREEN Bridge Open
- BLUE Travel With Caution
- YELLOW Reduced Speed Limit
- ORANGE Bridge Closed. Emergency Vehicles Only at Reduced Speeds
- RED Bridge Closed

Evaluation forms are intended to be filled out electronically, whereby, the resulting posting will be determined through an internal program developed from the expert opinions of the authors. Appropriate posting actions and associated recommendations are produced from the inspection results on the evaluation forms. The information gathered on these forms will also be used to prioritize follow-up inspections by trained bridge engineers and plan repair efforts.

2.1 Pre-Investigation Procedure

A pre-investigation procedure should consist of a rapid visual survey of all bridges in the region to identify the geographic extent of earthquake damage, obviously unsafe bridges or impassable roadways, and any other information that would affect the safety of the inspection personnel. Aerial views, local jurisdiction reports, and firsthand accounts may be used for this procedure. This pre-investigation process will be used to disseminate inspection teams in a safe and efficient manner. The inspection teams should strategically evaluate critical transportation routes that connect hospitals, schools, power centers, telecommunication centers, and cities first.

2.2 Investigation Procedure

The investigation procedure requires that inspection teams of at least two individuals make assessments of the structural and geotechnical post earthquake condition of the bridges. The inspection teams will fill out an electronic form for all components of the bridge structure. An internal program will provide the appropriate posting condition and associated recommendation based on whether the observed damage was none, minor, moderate or severe for each component. When a bridge has spans of different materials such as concrete, steel or timber, each span will be evaluated separately with the other bridge components in an independent analysis used by the program. The posting for the bridge will be based on the span type that produces the worst damage rating. When a bridge has multiple spans of the same material, the span with the worst rating will govern.

If the posting of the bridge structure is determined to be GREEN, traffic will be permitted to travel with no restrictions. A "Bridge Open" sign will be used to signify that the structure is safe for all traffic.

If the posting condition of the bridge structure is BLUE a "Travel With Caution" sign will be used and a maintenance evaluation will be required.

If the posting condition of the bridge structure is determined to be YELLOW, a "Reduced Speed Limit" sign will be used and a subsequent evaluation by a structural engineer will be required. The inspection team shall contact State Patrol for traffic control as this posting indicates a general risk of vehicle accident occurrence resulting from bridge damage. Barricades should be placed in an offset pattern so traffic would be restricted to a zig-zag flow at reduced speeds.

If the posting is determined to be ORANGE a "Bridge Closed. Emergency Vehicles Only at Reduced Speeds" sign will be used and a subsequent evaluation by a structural engineer will be required. This posting represents a significant risk of vehicle accident occurrence resulting from bridge damage, as well as, a potential risk to personal safety. The bridge must be closed to non-essential emergency vehicles. Emergency vehicles must proceed at reduced speeds. Shoring and bracing may be required at these bridge structures. The inspection team shall coordinate with State Patrol for these traffic restriction requirements and maintenance personnel for shoring and bracing needs.

If the posting of the bridge structure is determined to be RED, a "Bridge Closed" sign will be used and subsequent evaluation by a structural engineer will be required. The inspection team must coordinate with the State Patrol to stop traffic from crossing the bridge, radio for regional assistance to provide temporary barricades and inform the Transportation Cabinet of the closure. If any bridge structure is totally collapsed or completely nonfunctional, the structure should be posted as RED and a detailed post investigation completed later.

It is critical that the judgment of the inspection team be used to assess the overall condition of the bridge structure and interpret unanticipated damage patterns in determining the final posting results. The inspection team may override the posting and associated recommendations determined by the internal program by documenting the findings in the comment area of the investigation form.

The inspection form will also be used to make repair assessments and recommend immediate shoring and bracing or other remediation efforts to the damaged structure. Notification and coordination with the appropriate divisions and agencies should be made to implement these recommendations. If any hazardous condition is encountered during the inspection, such as, downed power lines, faulty traffic control devices or roadway obstructions, the appropriate authorities should be contacted in order to secure the area.

2.3 Post Investigation Procedure

Any structure posted as BLUE should be evaluated by maintenance personnel to remove or repair any damage to the bridge which would threaten the safety of the traveling public. Furthermore, a post investigation process should be conducted on all YELLOW, ORANGE, or RED posted structures by a professional structural engineer in the days following the seismic event. Post investigation teams will make a more detailed assessment of the bridges in the affected area and review any structure previously identified as requiring subsequent monitoring. Follow up inspections are always recommended after significant aftershocks that may further damage the bridge structure and require more stringent traffic limitations. Severely damaged structures may worsen due to aftershocks, traffic or gravity effects and thus need continual monitoring. The geotechnical and structural aspects required for this post investigation process is beyond the scope of this manual.

It is recognized that damage to foundation elements, piles, and footings cannot be readily inspected in a rapid damage assessment procedure. If damage were suspected, excavation procedures would be required but is considered beyond the scope of this manual. Likewise, access to concrete box girder openings or confined space entry could yield valuable information and may be considered necessary in a post investigation assessment.

3 RESOURCES

A successful post earthquake inspection depends on preparation, organization, coordination, communication and cooperation. The highway system is a particularly dangerous location after an earthquake and it is important to remember that the safety of the inspection teams is the number one priority. Inspection teams should include at least two individuals who have participated in routine practice drills prior to any post earthquake investigation. Below is a list of recommended equipment that should be available to the inspection teams. A review of this manual and equipment should be conducted on a semiannual basis.

3.1 Equipment

- Radio and cellular phone (with battery chargers)
- Walkie-talkies
- Mountaineering equipment for those trained to use it
- Paper copy of investigation manual and 20 copies of inspection forms. Alternately, computer tablets or electronic versions of the inspection forms may be used.
- Sketch pad, paper, pencils, and clipboard (tape recorder, optional)
- 100 foot tape, pocket tape
- Inspection mirror on swivel head for inaccessible areas
- Flashlight and extra batteries
- Camera and film (digital camera, if available)
- Boots and hip boots if wading is required
- Official identification
- Rugged clothing or coveralls
- Rain gear
- Safety vest
- Hardhat
- Ear plugs
- Safety glasses/goggles
- Gloves, leather
- Watch
- First aid kit with eye wash
- Fire extinguisher
- Binoculars
- Wire brush, shovel, and whiskbroom for cleaning
- Pocketknife
- Scraping tool
- Ladder
- Hand level
- Plumb bob
- Compass
- Feeler gauges for measuring crack widths and depth

- Large and small screwdrivers— Flathead and Phillips
- Pliers
- Geologist hammer
- Adjustable crescent wrench
- Cones and portable traffic barriers
- Speed limit signs
- Flagman's signal
- "Road Closed" signs
- GREEN, BLUE, YELLOW, ORANGE, RED posting signs

4 INSPECTION PROCEDURES

4.1 General

Highway bridges are composed of various structural components. They include the embankment, main spans, deck, abutments, bearings, and piers or columns. No two bridges are alike and some may not contain all of these components. Figures 1 and 2 show the key components of a typical bridge structure. The substructure portion of a bridge consists of the embankments, abutments, bearings, piers or columns, and foundation system. The supporting elements of the substructure (i.e. the piers or columns) may be a single pier, as shown in Figure 1, or have multiple columns within one or more piers. The superstructure portion consists of the main spans (girders) and deck. The main span of a bridge structure varies depending of the material components. It may be composed of concrete, timber, or steel elements. The main spans include the girder elements and truss members (including cross bracing and/or diagonals).

4.2 Departure Procedures

- Review the type and location of the bridge.
- Collect the necessary tools for the inspection.
- Anticipate the type of construction materials to be encountered and any special tools needed.
- Assign inspection responsibilities to the appropriate individuals.
- The inspection team should be separated at the bridge site at all times to assist in rescue efforts, if necessary.

4.3 Bridge Site Procedures

- Note inspectors' names and bridge identification information.
- Make a visual inspection of the entire bridge and note:
 - Embankment damage
 - Concrete, steel, or timber span damage
 - Deck damage
 - Abutment damage
 - Bearing damage
 - Pier or column damage.
- Never walk or drive immediately under or over the bridge until the safety of the environment has been assessed.
- Use caution when proceeding under or across a bridge structure, as aftershocks may further shift or cause collapse of an already precarious structure.
- The inspection team members should remain reasonably separated from each other and never go underneath the bridge at the same time.
- If any bridge structure is total collapsed or completely nonfunctional, the structure should be immediately posted as RED and no further inspection is required.

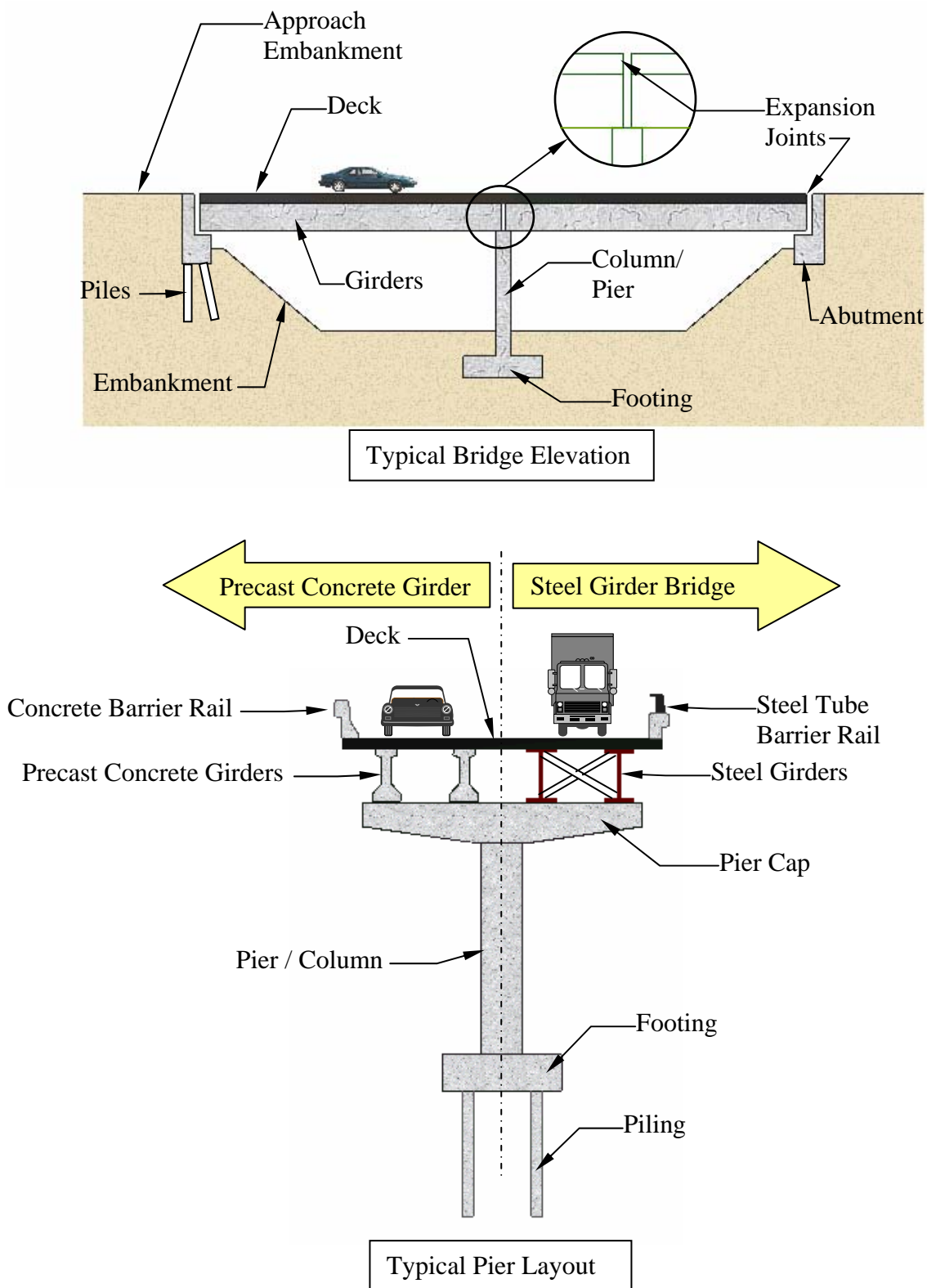


Figure 1 Structural components of a typical highway bridge structure

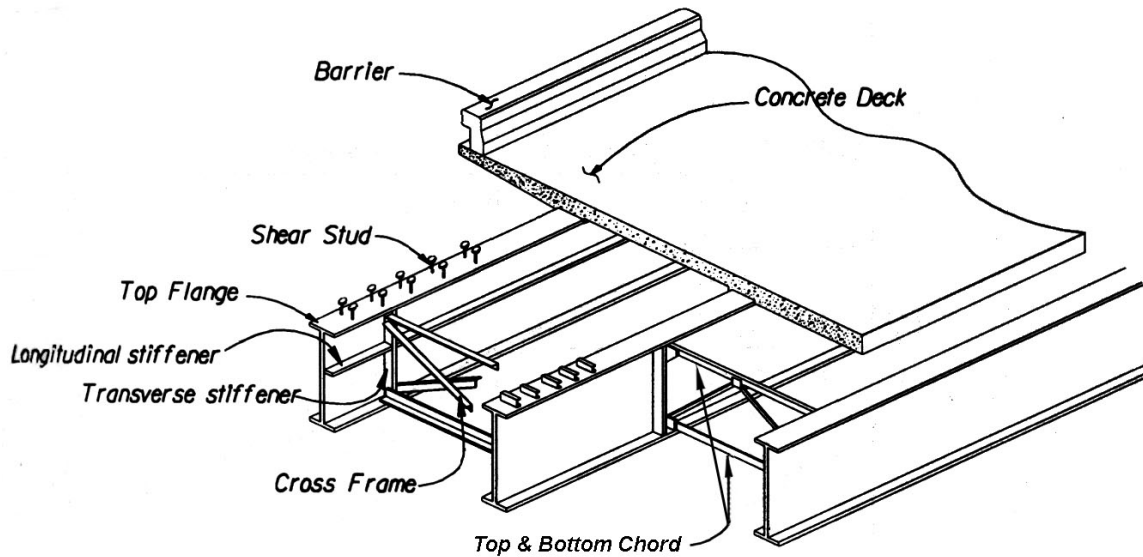


Figure 2 Typical components of a welded steel plate girder bridge (30)

- Proceed by inspecting the components of the bridge in the order in which they appear on the investigation form.
- Inspect each structural component in detail to determine level of damage:
 - None
 - Minor
 - Moderate
 - Severe
- Discuss the observations with the team members and come to a consensus.
- Fill out the investigation form and confirm the remediation recommendations and postings.
- Inform the appropriate authorities of reduced speed limits, traffic restrictions and barricade requirements.
- Barricades may be required at the bridge approaches or at the passages below.
- Take photos of the inspected bridge and its various components showing damage. When necessary for scale indications use a tape measure, person, clipboard, or other distinguishing objects to relate size variations.
- Keep a catalog of the photos indicating the type of damage, direction, and location of the photo (a tape recorder is often helpful). Record the photographer's initials, route and bridge number on the film roll.
- Post the bridge structure with the appropriate GREEN, BLUE, YELLOW, ORANGE or RED signs as determined from the investigation form.
- Implement the Recommendations made on the investigation form.

4.4 Bridges of Kentucky

Kentucky has a wide variety of bridge structures that compose its highway transportation system. A select group of the most common structural types are shown below.



Figure 3
Continuous Precast I-Girder Bridge (25)



Figure 4
Precast I-Girder Bridge (25)



Figure 5
Precast I-Girder Bridge (25)



Figure 6
Precast I-Girder Bridge (25)



Figure 7
Cast-in-Place Box Girder Bridge (25)



Figure 8
"Haunched" Concrete Girder Bridge (25)



Figure 9
"Haunched" Concrete Girder Bridge (25)



Figure 10
Welded Plate Girder Bridge (25)



Figure 11
Continuous Welded Plate Girder Bridge (25)



Figure 12
Continuous Welded Plate Girder Bridge (25)



Figure 13
Welded Plate Girder Bridge (25)



Figure 14
Welded Plate Girder Bridge (25)



Figure 15
Welded Plate Girder Bridge (25)



Figure 16
Welded Plate Girder Bridge (25)



Figure 17
Plate Girder Bridge with Steel Arch (25)

4.5 Embankment Damage

In recent earthquakes, the embankments to bridge structures are commonly known to suffer approach slab damage, settlement and side movement. If the vertical or transverse settlement is greater than 12 inches, the condition represents a significant hazard to the traffic and should be considered to be severe damage. Generally, most vehicles could be allowed to cross a bridge with severe vertical or transverse settlement after a complete stop at the settlement location. If the vertical or transverse settlement is between 6 inches and 12 inches the damage condition should be classified as moderate, while, settlement less than 6 inches is minor damage. Spalling and cracking of the approach slab is frequently observed even in moderate magnitude seismic events. Slope failures, soil liquefaction, soil fissures and differential settlement are common types of damage experienced at the side approaches or front embankment slopes at a bridge.



Figure 18 **Minor damage.** Ground crack extending diagonally down slope under the abutment. (1)



Figure 19 **Minor Damage.** Approach slab settlement at the abutment AC median shoulder. (1)



Figure 20 **Moderate Damage.** Settlement of the bridge approach slab. (1)



Figure 21 **Moderate Damage.** Approach settlement at the abutment. (2)



Figure 22 **Severe Damage.** Damage to the roadway due to fault rupture. (3)



Figure 23 **Total Failure.** Embankment settlement. (1)

4.6 Concrete Span Damage

Concrete spans should be inspected for flexural cracks, shear cracks and spalling at the bearings. Excessive deflection should also be noted, as this would indicate yielded reinforcement or prestressing strands that may not be capable of supporting necessary live loads. In concrete structures it is possible to tap on the section with a hammer and determine its integrity. A resulting high pitch sound indicates that the concrete section is solid, whereas, and a low pitch “thud” indicates the section is cracked. The bearing assemblies should be examined for cracking or spalling concrete. The girders should be inspected for any shifting or misalignment. Typically, precast, prestressed concrete girders are supported on neoprene pads in a formed key or slider type bearings, as shown in Figure 24.



Figure 24 An already corroded “slider” type bearing assembly is susceptible to transverse shearing forces induced by seismic demands and may pose a threat of collapse if the displacements become excessive once sheared. (25)



Figure 25 **Minor Damage.** Shear cracks have begun to develop near the supports of the beams. (1) (Photo modified by Tom Sardo to illustrate the increasing level of earthquake damage for illustrative and training purposes).



Figure 26 **Moderate Damage.** Cap beam damage. (4)



Figure 27 **Moderate Damage.** Flexural cracks in a concrete box girder bridge. (5)



Figure 28 **Severe Damage.** Excessive damage to the superstructure and the substructure has caused partial collapse to the bridge, rendering it unsafe for traffic. (1)



Figure 29 **Total Failure.** Collapse of simply supported precast, prestressed concrete girders. (4)

4.7 Steel Span Damage

Steel spans require careful inspection since the damage may not be as noticeable as in concrete components. Steel spans must be checked for local buckling of critical elements and damage to the chords or diagonals. All plates, hangers, and assemblies should also be carefully inspected. One may look for chipped paint or exposed primer, often of a different color indicating localized damage to a steel member (see Figures 33 & 34). Anchor bolts, which connect steel components to concrete components, such as a bearing assembly to a concrete pier, should be examined for failure at the concrete interface. All connections should be inspected for cracks in the welds and sheared or elongated bolts. Similar to tapping on concrete with a hammer to note its integrity, one may strike a bolt that has elongated and note the sound. A sharp ring indicates the bolt has not broken and a low pitch sound, or “thud”, indicates a broken bolt. Finally, all bolts should be intact and nuts tight. The girders should be inspected for any misalignment, cracking or cracked welds. Especially crucial are the “hanger pins” used to support suspended spans of a steel girder bridge. This detail is vulnerable to seismic attack and leads to complete loss of span support. See Figure 30.

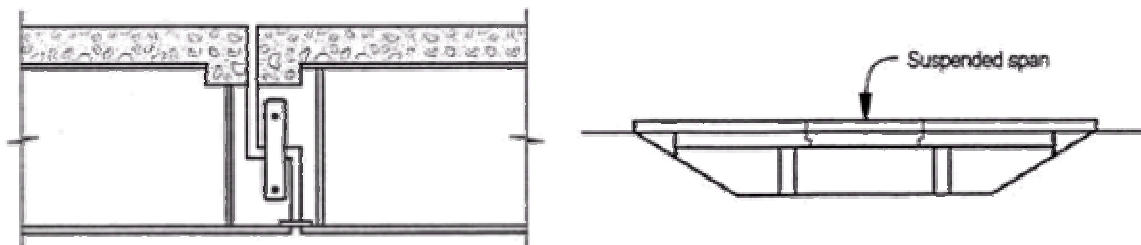


Figure 30 Suspended span detail in a steel girder bridge. (6)

A majority of the steel plate girder bridges in Western Kentucky along Interstate I-24 are multi-span with continuity provided over the supports, as shown in Figure 31, which do not employ the use of “hanger pins”. Because of this continuity, these types of structures provide an added redundancy against seismic attack due to the lack of expansion joints and the possibility of becoming unseated, as would be the case in a simply supported span.



Figure 31 Continuous steel plate girder bridge. (25)



Figure 32 **Minor Damage.** Buckled cross-bracing. (1)

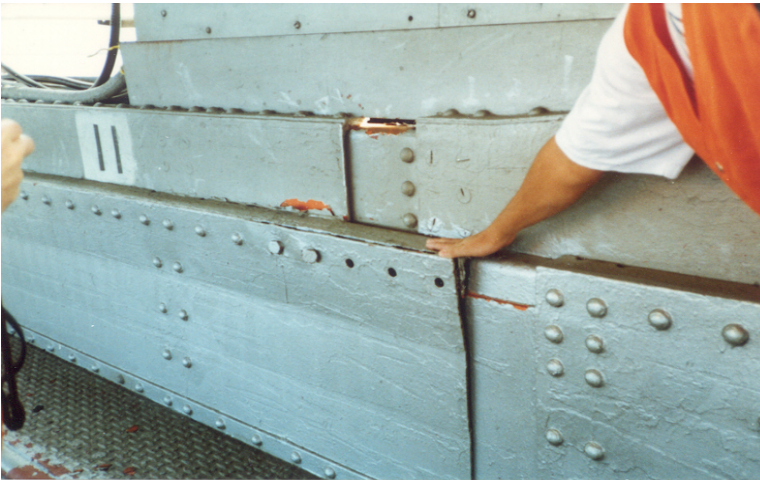


Figure 33 **Minor Damage.** Sheared rivets at the steel truss plate. (9)



Figure 34 **Moderate Damage.** Buckled flanges and webs of the steel girders and bearing failure. (10)



Figure 35 **Severe Damage.** Buckling of the steel girders. (1)



Figure 36 **Total Failure.** Collapse of the simply supported span due to anchor bolt failure and spalling of the concrete cover. (11)

4.8 Timber Span Damage

In general, timber span bridges perform quite well in major seismic events since they are rather flexible and have short span lengths. Timber span bridges should be checked for lateral instabilities that may cause the structures to lean. The connections should be examined for their integrity and alignment.



Figure 37 **Minor Damage.** Timber connection pulled apart from earthquake. Note the cracking near the support. This could be caused from shrinkage since it is perpendicular to the grain, however, since the bottom plate shows signs of displacement, it would indicate earthquake related damage. (29) (Photo modified by Tom Sardo to illustrate the increasing level of earthquake damage for illustrative and training purposes).



Figure 38 **Moderate Damage.** Lateral instability failure. The earthquake has caused the bridge to displace excessively in the longitudinal direction. The connection has failed and pulled away from the diagonal in the upper right of the photo. The top cap is still supported by the columns but in a very unstable configuration. (10) (Photo modified by Tom Sardo to illustrate the increasing level of earthquake damage for illustrative and training purposes).



Figure 39 **Severe Damage.** Lateral instability failure. The earthquake has caused the bridge to further displace to the left side of the photo, rendering it unsafe for traffic. (1) (Photo modified by Tom Sardo to illustrate the increasing level of earthquake damage for illustrative and training purposes).

4.9 Deck Damage

The deck of a bridge structure often reveals valuable information as to whether the structure has experienced sufficient forces or movement to cause significant damage. Major deck spalling, displacements at the expansion joints and excessive deflections within spans often indicate internal damage. Displacement of the longitudinal joints indicates displacements likely experienced at the top of columns. Bridges built on high skews will experience lateral movement perpendicular to the span and cause spalling of the barrier rail, curb, and damage to the guard rail. Generally, this type of damage does not represent a structural problem itself but may jeopardize the safety of the traveling public. Barrier rails can often be inspected for fresh scratches on scribe scripts or gaps in the rails to determine the magnitudes of recent movement.



Figure 40 **Minor Damage.** Three inches of transverse movement along the centerline. (8)



Figure 41 **Minor Damage.** Barrier rail crushing. (1)



Figure 42 **Moderate Damage.** Failed bearing pads and crushing at the hinge joint. Note the short seat length supporting the superstructure. (1)



Figure 43 **Severe Damage.** Deck cracking. (1)



Figure 44 **Severe Damage.** Overview of the shear failure in the deck. (1)

4.10 Abutment Damage

Longitudinal movement during an earthquake may damage the abutment backwall. More often than not, this type of failure is desirable, since the backwall will behave like a “fuse” and protect the supporting piles from seismic damage. However, excessive longitudinal movement is still undesirable, since this would require much larger support widths. Transverse movement may displace or crack the wingwalls, as well as, the abutment shear keys. The backwall and wingwalls may also suffer flexural or shear cracks. Loose or settled fill, slope failures, liquefaction, fissures and differential settlements at the base of the abutments may be observed as evidence of foundation movement and possible damage.



Figure 45 **Minor Damage.** Shear cracking at the abutment backwall and wingwall. (10)



Figure 46 **Minor Damage.** Intermediate shear key damage and longitudinal offset at the abutment. (5)



Figure 47 **Moderate Damage.** Longitudinal displacement at the abutment seat. (8)



Figure 48 **Severe Damage.** Foundation movement. Longitudinal displacement and rotation of the abutment footing. Notice the flexure and shear failure of the exposed piles. (10)



Figure 49 **Total Failure.** The shear key failed and the span unseated at the abutment. (1)

4.11 Bearing Damage

The continuity of joints in a bridge structure represents locations of greatest vulnerability during seismic events. Bearings at the abutments and span locations should be inspected for toppled assemblies, sheared or loosened bolts, sheared keeper plates and dislodged movement. In addition, the bearing seats should be checked for adequate seat width to support the adjoining spans. In general, a minimum of 4 inches should be maintained. This allows for 2 inches of cover for a concrete girder and 2 inches of cover for the

support. In that way, un-reinforced concrete will not be supporting un-reinforced concrete and result in a confinement failure. Tall rockers are subject to large vertical drops. A vertical drop of 6 inches to 12 inches should be considered as moderate damage. While, a vertical drop of more than 12 inches should be considered severe damage.



Figure 50 **No Damage.** Movement of the rocker bearing due to thermal loads. (13)



Figure 51 **No Damage.** Movement of the elastomeric bearing under thermal loads. (13)



Figure 52 **Minor Damage.** Steel bearing induced cracks. (8)



Figure 53 **Minor Damage.** Pounding at the midspan hinge. No superstructure unseating. (1)



Figure 54 Tall rocker bearings (> 6 inches) on short seats are especially vulnerable to collapse. Generally, if the bearing topples and stays seated, the resulting height of the vertical drop will render the bridge useless. (25)



Figure 55 **Moderate Damage.** Crushed bearing assembly. Also note the slightly elongated bolts. (1)



Figure 56 **Moderate Damage.** Sheared anchor bolts. (1)



Figure 57 **Severe Damage.** Displacement of the steel girder off the bearing support. (1)



Figure 58 **Total Failure.** Unseating at the expansion joint. (1)



Figure 59 **Total Failure.** Unseating of the superstructure at the pier. (3)

4.12 Pier or Column Damage

Concrete piers or columns may show flexural and shear cracks after an earthquake. If the cracks are superficial and if the concrete cover spalls over a limited area, the damage should be specified only as minor. However, if the concrete cover spalls over a large area and the cracks penetrate into the core of the column (defined by the area within the limits of the lateral confining steel, such as hoops, ties or spirals), the damage should be specified as moderate or severe and the structure should be shored. Since the typical reinforcing scheme is to use a #4 reinforcing bars or hoops at a 12-inch spacing, there is not much ductility capacity in these columns. Thus, there is not much room for judgment between the categories of moderate and severe. If a majority of the cracks are diagonal (indicating shear cracks), the condition should be assessed as severe, until further inspection can be completed. Buckled or fractured reinforcement is also indicative of severe damage. More often than not, the noted damage will be at the top or bottom of the columns or piers. The top of the columns should be investigated for column to cap joint connection damage. The bottom of the columns should be investigated for dislocated soil, liquefaction, fissures, and differential settlements as an indication of foundation movement and possible damage to the footings.



Figure 60 **No Damage.** Column movement evident by the ground cracking and displacement. (5)



Figure 61 **Minor Damage.** Shear key element damage. (10)



Figure 62 **Minor Damage.** Shear cracking of the concrete cover at the column base. (5)



Figure 63 **Minor Damage.** Torsional/shear cracking throughout the column length. (5)



Figure 64 **Moderate Damage.** Shear failure of the column. The cracks have propagated into the core concrete and the vertical bars are beginning to buckle. (5)



Figure 65 **Severe Damage.** Girder span was moved to the right, its concrete pedestal was rotated, and the girder span almost fell into the river. Note the shortening indicated by the buckling of the guardrail. (14)



Figure 66 **Severe Damage.** Shear failure in column. (1)

Figure 67 shows a bridge that had seven spans across the river, each supported by piers consisting of structural steel girders carrying a reinforced concrete deck. Two of the piers collapsed. The corresponding spans of the bridge collapsed and dropped into the river. The successive spans toward the west bank also dropped while one end of each span remained connected at the top of successive piers. The construction was such that one end of the girders was fixed and the other end was free to slide longitudinally off the pier after about 12 inches of movement.



Figure 67 **Total Failure.** Collapse of two piers that resulted in loss of support for the connecting spans. (15)



Figure 68 **Total Failure.** Failure of the concrete box girder at the face of the pier cap. (5)



Figure 69 **Total Failure.** Confinement failure in the column. (5)

5 KENTUCKY POST EARTHQUAKE INVESTIGATION REPORT

Inspector's Name & Affiliation: _____

Date and Time: _____

BRIDGE DESCRIPTION

GPS Location: Latitude Longitude Traffic Direction

Bridge Number: _____

Route: _____ Bridge Crossing: _____

STRUCTURE TYPES

- | | |
|---|---|
| <input type="checkbox"/> Concrete Arch | <input type="checkbox"/> Steel Arch |
| <input type="checkbox"/> Cast-in Place Concrete Box | <input type="checkbox"/> Steel Box Girder |
| <input type="checkbox"/> Concrete Slab | <input type="checkbox"/> Steel I-Girder |
| <input type="checkbox"/> PPCDU w/ Slab | <input type="checkbox"/> Steel Truss |
| <input type="checkbox"/> PPCDU w/o Slab | <input type="checkbox"/> Culvert |
| <input type="checkbox"/> Precast I-Girder | <input type="checkbox"/> Cable Stay |
| <input type="checkbox"/> RCDG (Concrete T-Girder) | <input type="checkbox"/> Suspension |
| <input type="checkbox"/> Timber Arch | <input type="checkbox"/> Unknown |
| <input type="checkbox"/> Timber Girder | <input type="checkbox"/> Other _____ |
| <input type="checkbox"/> Timber Truss | |

BEARING TYPES

- | | |
|--|--------------------------------------|
| <input type="checkbox"/> Steel Rocker | <input type="checkbox"/> Elastomeric |
| <input type="checkbox"/> Steel Roller | <input type="checkbox"/> Other _____ |
| <input type="checkbox"/> Steel Sliding | |

DAMAGE SCALE

Record the most severe damage anywhere within multi-span bridges and check all applicable boxes in the categories below.

	None	Minor	Moderate	Severe
EMBANKMENTS				
Approach slab damage	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Settlement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Side movement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CONCRETE SPAN COMPONENTS				
Flexural cracks	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Shear cracks	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spalling at bearings	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
STEEL SPAN COMPONENTS				
Local buckling	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Chords/Diagonals	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Connections	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

DECK

Displacement of longitudinal joints	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Displacement of expansion joints	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Guard rail/curb	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Deck cracking/spalling	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

ABUTMENTS

Backwall movement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wingwall movement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Flexure or shear cracking	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Foundation movement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BEARINGS

Toppling failure	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dislodged failure	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Confinement failure	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

PIERS/COLUMNS

Flexural cracks	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Shear cracks	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Column to cap joint damage	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Foundation movement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Local buckling	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

RECOMMENDATIONS

- ☐ **Low:** Safe for traffic
- ☐ **Guarded:** Travel with Caution
- ☐ **Elevated:** General risk of vehicle accident occurrence resulting from bridge damage. Traffic must proceed at reduced speeds.
- ☐ **High:** Significant risk of vehicle accident occurrence resulting from bridge damage, as well as, potential risk to personal safety. Bridge must be closed to non-essential vehicles. Emergency vehicles must proceed at reduced speeds. Shoring and bracing may be required.
- ☐ **Severe:** Bridge must be closed to all traffic.

POSTING

- ☐ **GREEN** (Post "Bridge Open" signs.)
- ☐ **BLUE** (Post "Travel With Caution" signs; Maintenance evaluation required.)
- ☐ **YELLOW** (Post "Reduced Speed Limit" signs; Structural Engineer evaluation required)
- ☐ **ORANGE** (Post "Bridge Closed. Emergency Vehicles Only at Reduced Speeds" signs; Structural Engineer evaluation required)
- ☐ **RED** (Post "Bridge Closed" signs; Structural Engineer evaluation required.)

COMMENTS

6 EXAMPLE INVESTIGATION REPORT

The following example shows a hypothetical bridge that was damaged after a moderately sized earthquake. The bridge is a 3-span, welded plate steel girder bridge that is simply supported at the piers. There are 3 columns per pier and the pier cap has a 12-inch support width. The abutments are “stub” abutments (or seat type) and have slider type bearings. The damage photos are listed in the order of recommended inspection and as shown on the investigation form. The investigation form is filled out showing the appropriate damage levels for this hypothetical bridge.



Figure 70 **Minor Damage.** Approach slab settlement at the abutment. (1)

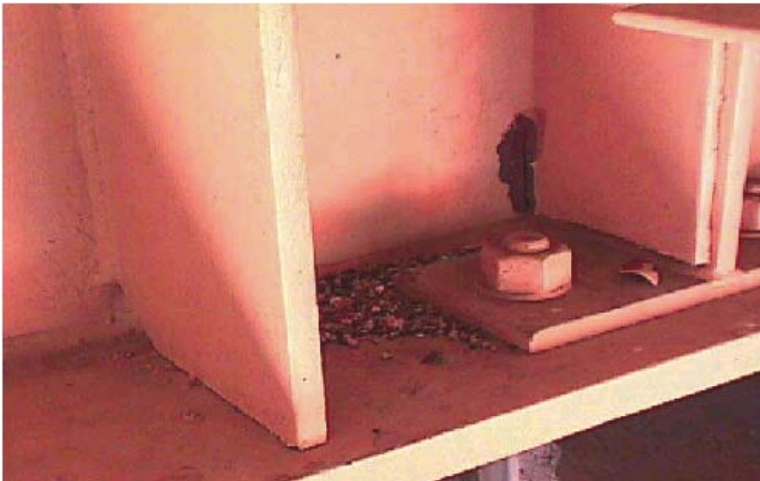


Figure 71 **Minor Damage.** Crack in the girder web/stiffener plate near the abutment. (8)



Figure 72 **Minor Damage.** Transverse movement of the abutment wingwall. (8)



Figure 73 **Minor Damage.** Shear cracking at the abutment wingwall. (10)



Figure 74 **Moderate Damage.** Anchor bolt spalling and minimal support at the top of the pier.

Minor Damage. Minor cracking of the barrier rail. (1)



Figure 75 **Minor Damage.** Shear cracking of the concrete cover at the column base. (5)

KENTUCKY POST EARTHQUAKE INVESTIGATION REPORT

Inspector's Name & Affiliation: Jane Inspector, Kentucky Transportation Cabinet

Date and Time: 06/14/2005 1500 hours

BRIDGE DESCRIPTION

GPS Location: Latitude 3640.928 Longitude 8726.28 Traffic Direction E-W

Bridge Number: 11-1234

Route: I24 Bridge Crossing: Dry Creek River

STRUCTURE TYPES

- | | |
|---|--|
| <input type="checkbox"/> Concrete Arch | <input type="checkbox"/> Steel Arch |
| <input type="checkbox"/> Cast-in Place Concrete Box | <input type="checkbox"/> Steel Box Girder |
| <input type="checkbox"/> Concrete Slab | <input checked="" type="checkbox"/> Steel I-Girder |
| <input type="checkbox"/> PPCDU w/ Slab | <input type="checkbox"/> Steel Truss |
| <input type="checkbox"/> PPCDU w/o Slab | <input type="checkbox"/> Culvert |
| <input type="checkbox"/> Precast I-Girder | <input type="checkbox"/> Cable Stay |
| <input type="checkbox"/> RCDG (Concrete T-Girder) | <input type="checkbox"/> Suspension |
| <input type="checkbox"/> Timber Arch | <input type="checkbox"/> Unknown |
| <input type="checkbox"/> Timber Girder | <input type="checkbox"/> Other _____ |
| <input type="checkbox"/> Timber Truss | |

BEARING TYPES

- | | |
|---|--------------------------------------|
| <input type="checkbox"/> Steel Rocker | <input type="checkbox"/> Elastomeric |
| <input type="checkbox"/> Steel Roller | <input type="checkbox"/> Other _____ |
| <input checked="" type="checkbox"/> Steel Sliding | |

DAMAGE SCALE

Record the most severe damage anywhere within multi-span bridges and check all applicable boxes in the categories below.

	None	Minor	Moderate	Severe
EMBANKMENTS				
Approach slab damage	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Settlement	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Side movement	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CONCRETE SPAN COMPONENTS				
Flexural cracks	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Shear cracks	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spalling at bearings	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
STEEL SPAN COMPONENTS				
Local buckling	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Chords/Diagonals	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Connections	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

DECK

Displacement of longitudinal joints	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Displacement of expansion joints	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Guard rail/curb	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Deck cracking/spalling	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

ABUTMENTS

Backwall movement	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wingwall movement	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Flexure or shear cracking	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Foundation movement	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

BEARINGS

Toppling failure	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Dislodged failure	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Confinement failure	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

PIERS/COLUMNS

Flexural cracks	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Shear cracks	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Column to cap joint damage	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Foundation movement	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Local buckling	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

RECOMMENDATIONS

- ☐ **Low:** Safe for traffic
- ☐ **Guarded:** Travel with Caution
- ☒ **Elevated:** General risk of vehicle accident occurrence resulting from bridge damage. Traffic must proceed at reduced speeds.
- ☐ **High:** Significant risk of vehicle accident occurrence resulting from bridge damage, as well as, potential risk to personal safety. Bridge must be closed to non-essential vehicles. Emergency vehicles must proceed at reduced speeds. Shoring and bracing may be required.
- ☐ **Severe:** Bridge must be closed to all traffic.

POSTING

- ☐ **GREEN** (Post "Bridge Open" signs.)
- ☐ **BLUE** (Post "Travel With Caution" signs; Maintenance evaluation required.)
- ☒ **YELLOW** (Post "Reduced Speed Limit" signs; Structural Engineer evaluation required)
- ☐ **ORANGE** (Post "Bridge Closed. Emergency Vehicles Only at Reduced Speeds" signs; Structural Engineer evaluation required)
- ☐ **RED** (Post "Bridge Closed" signs; Structural Engineer evaluation required.)

COMMENTS

7 POST EARTHQUAKE INVESTIGATION TAGS

**KENTUCKY POST EARTHQUAKE
INVESTIGATION TAG**

GREEN

Bridge Open

Inspector's Name & Affiliation: _____

Date: _____

Time: _____

GPS Location: Latitude _____ Longitude _____ Traffic Direction _____

Bridge Number: _____

Route: _____

Bridge Crossing: _____

Remarks: _____

KENTUCKY POST EARTHQUAKE INVESTIGATION TAG

BLUE

Travel With Caution

Inspector's Name & Affiliation: _____

Date: _____

Time: _____

GPS Location: Latitude _____ Longitude _____ Traffic Direction _____

Bridge Number: _____

Route: _____

Bridge Crossing: _____

Remarks: _____

KENTUCKY POST EARTHQUAKE INVESTIGATION TAG

YELLOW

Reduced Speed Limit

Inspector's Name & Affiliation: _____

Date: _____

Time: _____

GPS Location: Latitude _____ Longitude _____ Traffic Direction _____

Bridge Number: _____

Route: _____

Bridge Crossing: _____

Remarks: _____

KENTUCKY POST EARTHQUAKE INVESTIGATION TAG

ORANGE

Bridge Closed.
Emergency Vehicles Only at
Reduced Speeds

Inspector's Name & Affiliation: _____

Date: _____

Time: _____

GPS Location: Latitude _____ Longitude _____ Traffic Direction _____

Bridge Number: _____

Route: _____

Bridge Crossing: _____

Remarks: _____

KENTUCKY POST EARTHQUAKE INVESTIGATION TAG

RED

Bridge Closed

Inspector's Name & Affiliation: _____

Date: _____

Time: _____

GPS Location: Latitude _____ Longitude _____ Traffic Direction _____

Bridge Number: _____

Route: _____

Bridge Crossing: _____

Remarks: _____

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